Earliest-Deadline Scheduling Using Discrete Service Bit Rates for CDMA Data Networks

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***Abstract* — Radio resource management is one of the critical functions for mobile wireless networks. The optimal utilization of network resources and the capacity to fulfill quality of service requirements are key requirements for 3rdG networks operations. Several burst admission and scheduling algorithms were proposed in the literature but most focus on the use of continuous service bit rates. In this study, we modify two widely cited algorithms to utilize discrete service bit rates. The proposed algorithms, DEDF and DPEDF are compared against the original continuous bit rate counterparts in terms of network throughput, power utilization, and packet discard rate for typical 3G network deployment parameters. Results indicate the use of discrete service rate reduces maximum network throughput and lowers the power utilization. Finally, the study also evaluates the effect of various packet delay thresholds on the overall performance of the network.**

***Index Terms* — Code Division Multiple Access, Load Management, Scheduling.**

I. INTRODUCTION

Mobile and wireless computing are fast growing technologies that are making ubiquitous computing a reality. Internet based applications on wireless networks are expected to be the dominant applications. This means future wireless networks (3rd & 4th Generation) should support heterogeneous and diverse quality of service (QoS) guarantees. Again, CDMA will be the widely deployed air interface for next generation wireless networks [1]. Therefore, traffic scheduling is essential for future CDMA networks to provide efficient management of the radio resources and to support the required (QoS) guarantees.

Scheduling is a time domain approach of resource management through which more than one user can share the same resource at different times. In wireless networks, the scheduling algorithm determines the transmission order of packets on the outgoing links and, thus, it has a direct impact on packet delays and achievable throughput.

A number of scheduling algorithms for CDMA data network were proposed and studied considering continuous range of service bit rate. A rate processor sharing algorithm is proposed in [2] for scheduling of downlink traffic, followed by further work in [3] and [4]. In [3], downlink scheduling based on the earliest packet deadline (EDF) for CDMA data networks has been discussed. The algorithm is later modified to allow more than one transmission per scheduling interval for better utilization of the system power. The new algorithm is called Powered EDF (PEDF) [4]. Further modification to PEDF lead to the Head of Line PsuedopRObability (HOLPRO) as specified in [5]. HOLPRO utilizes the packet length to assign a pseudo probability number used to priorities users' queues. All of these scheduling algorithms (RPS, EDF, PEDF, HOLPRO, etc) consider continuous bit rates, where an assigned bit rate ranges from zero to infinity and is calculated by dividing the packet size by the scheduling interval.

Focusing on discrete service bit rates, the study in [6] considered discrete scheduling intervals and variable users' channel conditions. With these assumptions, the authors show that the Largest Weighted Delay First (LWDF) scheduling scheme provides good quality of service (QoS). The scheduling algorithm known as Prediction based Delay-Constrained Shortest Transmission Time First (PDSTTF) is introduced in [7] together with its modified version M-PDSTTF. Using discrete transmission rates, the study shows that PDSTTF and its derivative are both superior to the EDF and HOLPRO algorithms specified in [3] and [5], respectively, in terms of packet loss probability. In addition, the study assumes multi-code capability of users, where more than one downlink transmission can be directed to any one user. However, no further characterization of PDSTTF or M-PDSTTF is provided. In [8] the authors present an analytic study for an optimal discrete one-rate scheduler for power-efficient transmission over wireless links. The study takes into account delay constraints and provides performance bounds for networks supporting multi-rate schedulers.

In this paper, we assume that our concerned transmitter can transmit only at a finite set of pre-configured rates. As with 1xRTT, the first deployed version of cdma2000, we assume the network supports powers-of-two multiples of the basic rates (9.6 kb/s for rate set 1 and 14.4 kb/s for rate set 2). The primary objective of this paper is to modify EDF and PEDF; two important members of the deadline-based scheduling algorithms with the constrained transmission rates. The new algorithms: discrete EDF (DEDF) and discrete PEDF (DPEDF) are characterized, assuming single code capability for user terminals, in terms of overall network throughput, power usage, and packet discard rate. The evaluation of DEDF and DPEDF is performed using typical 1xRTT deployment parameters. Furthermore, a comparative study of continuous service rates versus discrete service rates is also presented.

The organization of the paper is as follows. First, the modified EDF and PEDF algorithms are described in section 2 while the simulation model and network parameters are presented in section 3. Section 4 presents the performance results for the scheduling algorithms. Finally, the conclusions and acknowledgments are stated.

II. DISCRETE EARLIEST DEADLINE ALGORITHMS

Deadline-based scheduling algorithms are among the most widely researched algorithms for use in CDMA data networks. EDF and PEDF are the two key members of these algorithms and are characterized in [3] and [4], respectively. In this section we present two modifications to limit the selected service rates to a finite set supported by the network. Throughout the rest of the paper, the supported set of rates is given by the set $V = \{R_i : R_i = 2^i R_b, i = 0,1,...,5\}$, where R_b is the basic service rate. For the purpose of the algorithms outlined below, we define an auxiliary set $V' = \{0, R_0, R_1, R_2, \ldots, R_5, \infty\}$ where the rates zero and infinity are added to the set. It is clear that the minimum supported rate is $R_0 = R_b$, while the maximum supported rate denoted by R_{maxD} is equal to R_5. As with the original algorithm, the time access is divided into equal time slots, each is of length *SlotDuaration* seconds. The following specifies both algorithms, DEDF and DPEDF.

A. Discrete Earliest Deadline First (DEDF):

DEDF similar to EDF serves only one transmission per time slot. During each time slot a user's packet will be selected from the head of queue on the basis of smallest packet delay. The concerned single transmission can utilize all allocated traffic power in the network, if needed. When the packet latency exceeds D_{max}, then the packet is discarded.

The steps of the EDF algorithm [4][3] for continuous service rates are modified to support a discrete bit rate set. The outline of the modified algorithm is as shown below:

```
0. For every time slot on the time axis
1. Find packet with earliest deadline to serve; If all arrivals are exhausted, goto step 4
2. Compute required bit rate to serve full packet – $R_{req}$ = PacketsSize/SlotDuration
3. Compute $R_{reqD}$ = minimum rate in set $V' \geq R_{req}$ ,
        3.1 if $R_{reqD} = \infty$ than $R_5$ is not sufficient to exhaust packet during scheduling interval
                3.1.1 Calculate $R_{max}$ based on total available power
                3.1.2 Find $R_{maxD}$ = maximum rate in set $V' \leq R_{max}$
                3.1.3 Assign $R_{maxD}$
                3.1.4 Calculate number of transmitted bits; Update packet size field
                3.1.5 Update statistics
                3.1.6 Goto 0
        3.2 Else assign $R_{reqD}$
        3.3 Update statistics
        3.4 Get next packet
        3.5 Goto 0
4. End simulation; Display statistics
```

B. Discrete Powered Earliest Deadline First (DPEDF):

The original PEDF amends the shortcoming of EDF where only one transmission is served per time slot, by allowing more than one simultaneous transmission in an attempt to exhaust all available power. For every time slot, the algorithm identifies the candidate packet and assigns it a service bit rate. It computes remaining traffic power, if any, and attempts to use it for service of the next candidate packet. If the remaining power is not sufficient to serve the full packet, then the packet is served partially with the remaining part deferred for service in the next scheduling interval. The above process guarantees full utilization of the traffic power budget for sufficiently high loads. Packets served during one time slot may belong to one or more users. Unlike the original algorithm specified in [4], and its derivatives HOLPRO [5] and PDSTTF [7], we do not assume multi-code capability of the mobile terminal. In the preceding studies, more than one transmission destined for the same mobile required distinct CDMA codes. However, in this study it is assumed that all packet transmissions for a user will utilizes the same code. The outline of the algorithm is as follows:

```
0. For every time slot; If all arrivals exhausted goto 5
1. Pavail ← total traffic power
2. Add to queue all packets that have arrived so far
3. Fetch packet from queue – If end of queue Goto 0
4. Attempt to service Packet
        4.1 If user is not on already on air, use procedure similar to DEDF to determine $R_{reqD}$;
        4.2  Else, update $R_{ReqD}$ for user to account for this new packet
        4.3  Calculate $P_{req}$ ← power required to support all simultaneous transmissions
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        4.4  If $P_{req} \le Pavail$
                4.4.1 Update Pavail
                4.4.1 Get next packet
                4.4.2 Goto 3
        4.5  Else packet can not be served fully
                4.5.1  Find $R_{maxD}$ from set V' that can be
                supported
                4.5.2  Compute number of transmitted bits;
                update packet size field
                4.5.3 Update statistics
                4.5.4 Goto 0
5. End simulations; Display statistics
```

III. SIMULATION MODEL

The main objective of this paper is to study the performance of the DEDF and DPEDF algorithms and compare them against their continuous service rate versions assuming network parameters that may be used for a typical 1xRTT deployment scenario. The following model has been implemented and simulated.

A. Traffic Modeling

As the original studies in [3][4][5] and for the purpose of comparing results, we employ the same on-off model to generate bursty data traffic. The on-off durations are exponentially distributed. During the on period, packets arrive according to a Poisson process while no arrivals occur during the off period. The packet size is also exponentially distributed. For the simulation, the following parameters are considered:

- Mean on and off periods are 0.2 and 1.0 seconds, respectively
- Within the on period arrival rate of packets is equal to 20 packets per second.
- Mean packet size 10000 bits.

B. Network Modeling

For the network layout, the study considers a multi-cell service area consisting of the cell of interest and two tiers of interfering cells. Each of the 19 cells transmits at the same power level. Furthermore, the simulation assumes equal loading for the cell of interest and for all 18 interfering cells. For every iteration, N users are located uniformly in the cell of interest and then the basestation in the cell of interest starts downlink traffic service till all packet arrivals are exhausted.

The simulation utilizes the Hata RF propagation model to calculate the path loss gains associated with every pair of transmit-receive locations. The path loss between i^{th} user and the j^{th} cell is denoted by L_{ij}. If the total basestation transmit power is Pt, then it is assumed that β $(0 < \beta < 1)$ fraction of Pt is allocated for overhead channels. This means traffic channels can be allocated a maximum power, *Pavail*, equal to $(1-\beta)Pt$ at any iteration. In addition, transmissions on the forward link are not assumed to be perfectly orthogonal. Rather, an orthogonality loss factor, ρ $(0 < \rho < 1)$, is also considered. A value of ρ equal to zero corresponds to perfectly orthogonal downlink transmissions. Finally, burst admission control is based on the fact that assigned bit rates, $\{R_1, R_n, \ldots, R_m\}$ for all ongoing transmissions must satisfy the following signal quality formula

$$\left(\frac{E_b}{N_0}\right)_i \ge \left(\frac{E_b}{N_0}\right)_{Threshold} \qquad i = 1,2,\ldots,m$$

The link $(E_b/N_0)_i$ is given by

$$\left(\frac{E_b}{N_0}\right)_i = \frac{W}{R_i}\frac{L_{i0} \times P_i}{\rho L_{i0}\left(\sum_{j=1, j\neq i}^{m} P_j + \beta Pt\right) + \left(\sum_{j=1}^{m} P_j + \beta Pt\right)\sum_{k=1}^{18} L_{ik}}$$

for $i=1,2, \ldots, m$. $(E_b/N_0)_{Threshold}$ is the minimum required signal quality for sustained communications, L_{ik} is the path loss coefficient between the i^{th} $(i = 1, 2, \ldots, m \le N)$ user and the k^{th} $(k = 0, 1, \ldots, 18)$ cell; N is the total number of users in the 0^{th} cell. The first summation term in the denominator of the above equation represents the interference power resulting from ongoing transmissions on the downlink in the same cell, while the second summation term represents the inter-cell interference power. The term $f_i = \sum_{k=1}^{18} L_{ik} \big/ L_{i0}$ represents the ratio of sum of path loss coefficients between the i^{th} user and all the interfering cells to the path loss coefficient between the i^{th} user and the cell of interest. The quantity f_i depends only the user location and is evaluated off-hand and approximated using a polynomial of the 7^{th} degree.

IV. RESULTS AND DISCUSSION

Table I summarizes the used network parameters. These parameters are used throughout this study unless specified otherwise.

TABLE I: SIMULATION PARAMETERS

Parameter	Value	Parameter	Value
β	0.2	$(E_b/N_0)_{Threshold}$	5 dB
ρ	0.1	R_b (basic rate)	9.6 kb/s
W	1.25 MHz	R_5 = *RmaxD* (max service rate)	307.2 kb/s
Pt	24 Watts	S (scheduling slot duration)	20 msec

The study evaluated the throughput in kb/s, the power utilization in Watts, and the packet discard or failure rate, all as a function of offered load. The offered load is varied by increasing the number of users in the cell of interest.

Fig. 1 and Fig. 2 show a comparison between the performance of EDF and PEDF on one side, and DEDF and DPEDF on the other side. As expected, the use of discrete service bit rate leads to a significant reduction in maximum network throughput. For example, EDF is capable of achieving a maximum throughput of 350 kb/s while the maximum throughput for DEDF is only 220 kb/s for the same networking parameters. Again, for DPEDF the maximum throughput is 400 kb/s which is 150 kb/s (or 27%) lower than that for the continuous service rate counterpart. It should be noted that this is not a reflection of the inefficacity of the discrete rate algorithms, but rather the optimism of the original continuous bit rate algorithms. As mentioned above, deployed 3G networks, at least in their initial phases, will use discrete service bit rates. The corresponding network power utilization is shown in Fig. 1.b and Fig. 2.b. It is worth noting that while PEDF is able to utilize 100% of the total traffic power ($\left(\left(1-\beta\right)\times Pt = 19.2 \text{ Watts}\right)$, its discrete version is only able to utilize 52% or 10 Watts. Furthermore, our results show that the packet discard probabilities experience slight reduction due to the discretization process. Finally, Fig. 1 and Fig. 2 also show that results are insensitive to packet delay thresholds ranging between 100 msec and 500 msec.

In Fig. 3 and Fig. 4 we focus on the delay threshold constraint. We vary the threshold from 500 msec to as low as 1 msec. It can be seen that the stricter delay thresholds lead to situations where more offered load is required to allow the network to reach its maximum throughput since most of the incoming packets violate the delay threshold and thus discarded. This maximum throughput is independent of the delay threshold. This is of course at the expense of higher rates of packet failure as depicted in Fig. 3.c and Fig. 4.c for the DEDF and DPEDF algorithms, respectively. The sensitivity to the delay threshold is expected to be mainly a function of the traffic generator statistics.

V. CONCLUSIONS AND REMARKS

Efficient scheduling algorithms are necessary to optimize the use of the limited radio resources and to provide quality of service for subscribers. Burst rate admission and scheduling are two important components in providing the above requirement. In this paper we considered a modification of two continuous service bit rate schemes, under the assumption of single code capability on the terminal side, and presented their discrete counterparts DEDF and DPEDF. Furthermore, using typical deployment scenario of 3G mobile CDMA network, performance figures in terms of throughput, power utilization, and packet discard rate were evaluated as a function of offered load. As expected, the discrete service bit rates lead to significant reduction in the overall throughput and prevent the 100% utilization of total base station traffic power. Furthermore, the study also examined the effect of packet delay threshold on the overall performance.

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REFERENCES

[1] Hai Jiang, and Weihua Zhuang, “Quality-of-service provisioning in future 4G CDMA cellular networks,” *IEEE Wireless Communications*, vol. 11, no. 2 , pp. 48-54, April 2004.

[2] K. Kumaran, and P. Whiting, “Rate Processor Sharing: A Robust Technique for Scheduling Downlink Data Transmissions in CDMA Wireless,” Technical Report BL0112120-990809-17TM, Bell Labs, 1999.

[3] M.Andrews, K.Kumaran, K.Ramanan, and A.Stolyar, P.Whiting, “Data Rate Scheduling Algorithms and Capacity Estimates for the CDMA Forward Link,” Bell Labs Technical Memorandum BL0112120-990922-32TM, 1999.

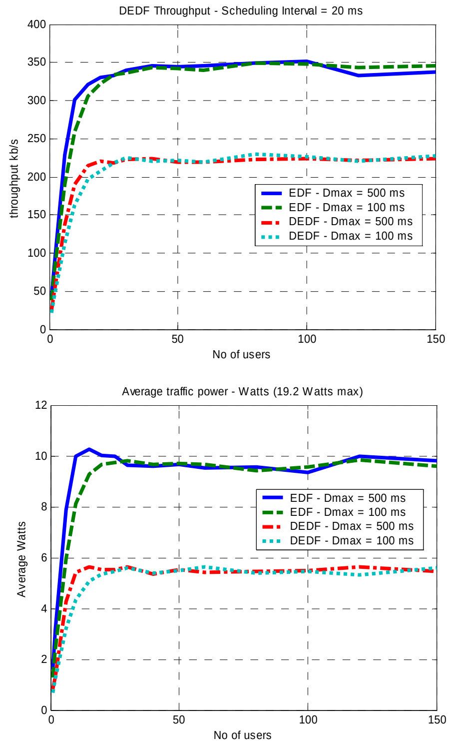
[4] Aikaterini C. Varsou, Howard C. Huang, and Laurence Mailaender, “Rate Scheduling for the Downlink of CDMA Mixed Traffic Networks,” *IEEE WCNC 2000*, vol. 1, pp. 370-374, 23-28 September 2000.

[5] Aikaterini C. Varsou, and H Vincent Poor, “HOLPRO: A New rate scheduling Algorithms for the Downlink of CDMA networks,’ *IEEE Vehicular Technology Conference*, Fall 2000, pp. 948-954.

[6] M. Andrews, K. Kumaran, K Ramanan, A. Stolyar R. Vijayakumar, and P.Whiting, “CDMA Data QoS Scheduling on the Forward Link with Variable Channel Conditions,” Technical report, Bell Laboratories, Lucent Technologies, 2000.

[7] Zhuo Gao, Yu Wang, and Shao-qian Li, “A Packet Scheduling Scheme in Wireless CDMA Data Network,” *IEEE International Conference on Communications, Circuits and Systems*, West Sino Expositions, vol. 1, pp. 211 – 215, 2002.

[8] P. Shah, and A. Karandikar, “Discrete Rate Scheduling for Power Efficient Transmission over Wireless Link,” *International Conference On Communication And Broadband Networking (ICBN`04)*, Kobe, Japan, April 7 - 9, 2004.



a)

b)

Fig. 1. EDF versus DEDF (discrete EDF).

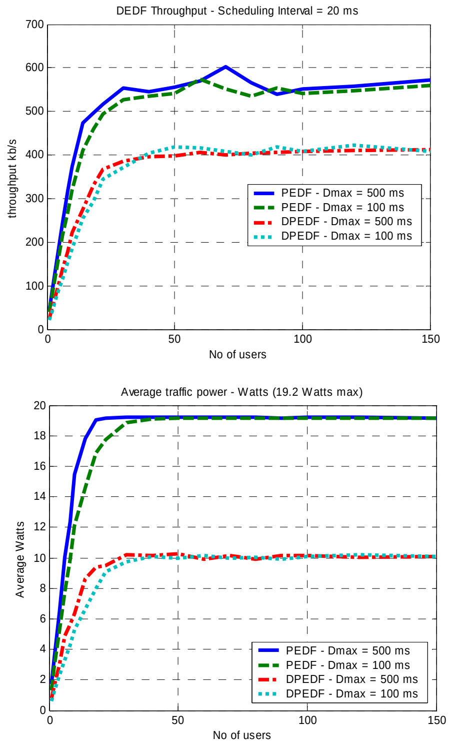


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Fig. 2. PEDF versus DPEDF (discrete PEDF).

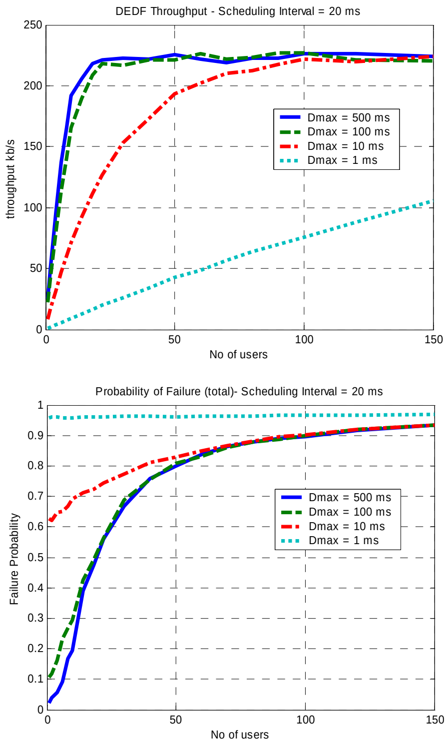

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Fig. 3. DEDF (discrete EDF) performance for different delay thresholds (D_{max}).

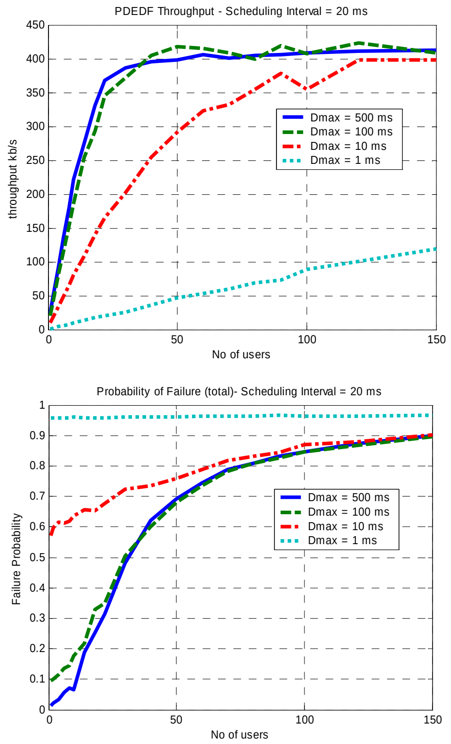

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Fig. 4. DPEDF (discrete PEDF) performance. for different delay thresholds (D_{max}).